Signal Processing Laboratory

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SAR: A Pictorial Résumé

\[ \text{pixel} = \frac{A}{\text{amplitude}} \exp(j\varphi) \begin{cases} \text{phase} & \text{InSAR} \\ \text{polarisation state} & \text{PolSAR} \end{cases} \begin{cases} \text{focusing} \\ \text{post-processing} \end{cases} \]

Every pixel tells a story
PRE-PROCESSING:
SAR focusing

- SpotLight SAR: High resolution
- Stripmap SAR: Medium resolution
- ScanSar & TopSAR: Low resolution

Different approaches of azimuth focusing
- w-k processor
- Chirp scaling processor
- Chirp-Z based processor

POST-PROCESSING:
Application oriented

- SAR Interferometry (InSAR)
- Geocoding & Geoprojection
- Differential SAR interferometry (DInSAR)
- Coherence Tracking
- SAR Polarimetry (PollnSAR)
- SAR Polarimetric Interferometry (PollnSAR)
- Multi-Chromatic Analysis
- Spectral Coherence
- Split-Band Interferometry (SBInSAR)
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\[
\text{pixel} = \frac{A}{\text{amplitude}} \exp(j \phi) \begin{pmatrix} \text{phase} \\ \text{polarisation state} \end{pmatrix} \begin{pmatrix} \text{SAR} \\ \text{InSAR} \\ \text{PolInSAR} \end{pmatrix}
\]
The raw image

The focused image

\[ \text{pixel} = A \exp (j \phi) \mathbf{p} \]
Buenos Aires from Space

ERS raw data
- processed at Cordoba ground station
- CSL processor
Recent development:
A part (burst) of a focused Sentinel-1 raw data: TopSAR Processor

TopSAR mode: Antenna steered not only in range but also in azimuth

*Incident beam moving from backward to forward and at different ranges on the ground* $\rightarrow$ *wide ground swath*
SAR Interferometry aims:
- To produce **Digital Elevation Models**
- To perform **coherence analysis for change monitoring and multi-chromatic analysis**

  to obtain scene characteristics:

- Soil moisture
- Crop stage
- Land use
- Human pressure
- Forest fires
- Landslides
- Floods
- ...
SAR Post-Processing: InSAR

Digital Elevation Models

Pass 1
Pass 2

Interference pattern

\[ \gamma = \frac{|\langle s_1s_2^* \rangle|}{\sqrt{\langle s_1s_1^* \rangle \langle s_2s_2^* \rangle}} \]

InSAR Processing steps:
- Co-registration
- Interpolation
- InSAR product generation
  - Amplitude/intensity images
  - Coherence image
  - Interferogram
- Phase unwrapping
- Geo-projection

\[ \text{pixel} = A \exp (j\phi \vec{p}) \]
Example: The Peninsula Valdes
A relief map of the Liège region, obtained by applying the interferometric technique to one ERS-1 image and one ERS-2 image (ESRIN Contract Nr. 12159/96/I-HGE "Quality Assessment of InSAR Topographic Mapping").
Recent development:

Wide-swath SAR: burst acquisition
Interferogram from a S1 TopSAR pair

\[ \text{pixel} = A \exp (j\phi \vec{p}) \]

After burst synchronization
InSAR for Change Detection

Temporal Coherence follow-up as a tool for change monitoring

*Interferometric coherence map of InSAR pair over Belgium*

- InSAR Coherence losses between the 2 SAR acquisitions is an important information channel on how the scene is changing:
  - Human activity
  - Vegetation density
  - Crop stage


**Results**

Relationship between plant height and coherence evolution with time (ex: potato and winter wheat).

Mean error of 7 cm seems compatible with information requirements for a crop monitoring system.
Coherence-Based Change Detection

\[ \text{pixel} = A \exp (j\phi) \]

An Example of change ….

Optical image

InSAR coherence showing vehicle tracks
Coherence-Based Change Detection: Recent example

Greenland wildfire
First observed on July 31, 2017
Coherence-Based Change Detection: Recent example

Greenland wildfire - Sentinel2 observation (8 August)
Coherence-Based Change Detection: Recent example

Greenland wildfire - Sentinel1 observations

Fire extension monitoring using 6-days Sentinel1A - Sentinel1B coherence layers
Coherence-Based Change Detection: Recent example

Greenland wildfire - Sentinel1 observations

- Fire full extension on August 17, 2017
  ➡ Estimated burnt surface: 21.8 km$^2$
SAR Post-Processing: WBInSAR

Wide-band Interferometry between sub-bands

\[ \text{pixel} = A \exp \left( j \phi \right) \vec{p} \]

Spectral coherence estimation

Target detection
Differential SAR Interferometry aims to retrieve information not related to the topography:

To measure and monitor local displacements

- Cities subsidence due to
  - Excessive water pumping
  - Mining activities
  - ...
- Dykes monitoring
- Glaciers
- ...

\[
pixel = A \exp (j \phi \vec{p})
\]
A spectacular result of radar interferometry: the interference pattern reflects the terrain displacements due to the Landers (California) earthquake in June 1992. Displacements of only 28 mm can be detected despite of the altitude (800 km) from which the images were acquired. The fracture fault can be seen on the right, where the fringe density is the highest. This interferogram covers an area of 50 km x 50 km (SSTC Contract No T3/12/012 "Neotectonic Study in Hill and Mountain Countries: an Interferometry Application").
Glacier monitoring: Shiraze glacier - Antarctica

\[ pixel = A \exp (j\phi \vec{p}) \]
Polarimetric SAR → information on scattering mechanisms

- In full-polarimetric SAR systems, the signal is **sent and received** alternatively along **two orthogonal polarizations** (Horizontal and Vertical)
- The system allows getting **four polarization scheme in a single acquisition**
- The complete scattering matrix is obtained

\[
\begin{pmatrix}
E_H^r \\
E_V^r
\end{pmatrix}
= \frac{e^{-jk}}{kr}
\begin{pmatrix}
S_{HH} & S_{HV} \\
S_{VH} & S_{VV}
\end{pmatrix}
\begin{pmatrix}
E_H^t \\
E_V^t
\end{pmatrix}
\]

**Allows classification of scatterers**

\[
U_{int} = -\vec{\mu}.\vec{E}
\]
Polarimetric SAR:
Information on scattering mechanisms

Example: VV, HH and HV images
(Images produced at CSL, ESAR polarimetric data provided by the DLR)

\[ \text{pixel} = A \exp(j \phi) \hat{p} \]
Polarimetric Decomposition for classification

• Several decompositions are possible
  – Example: Pauli decomposition

\[
\begin{pmatrix}
S_{HH} & S_{HV} \\
S_{VH} & S_{VV}
\end{pmatrix} =
\begin{pmatrix}
k_1 & 0 \\
0 & k_2
\end{pmatrix}
+ \begin{pmatrix}
k_2 & 0 \\
0 & k_3
\end{pmatrix} + \begin{pmatrix}
k_3 & 0 \\
0 & k_1
\end{pmatrix}
\]

\[\Rightarrow \vec{k} = \begin{pmatrix}
k_1 \\
k_2 \\
k_3
\end{pmatrix} = \frac{1}{2} \begin{pmatrix}
S_{HH} + S_{VV} \\
S_{HH} - S_{VV} \\
S_{HV} + S_{VH}
\end{pmatrix}\]

\[[T] = \vec{k} \cdot \vec{k}^\dagger\]
Polarimetric Decomposition for classification

- **H-A-\(\alpha\) Decomposition**
  
  - Based on the eigen vectors decomposition of the coherency matrix: the so called H\(\alpha\) decomposition revealing different backscattering processes

\[
pixel = A \exp (j \phi) \vec{p}
\]

Anisotropy = Red  Entropy = Green  
Alpha = Blue
InSAR + PolSAR \rightarrow \text{PollInSAR processing}

provides a combined sensitivity to the \textit{vertical} distribution of scattering mechanisms.

- Improvement of scatterers classification
- Forest height retrieval
Each SAR acquisition of an interferometric pair is made of three polarimetric channels (HH, VV and HV)

\[ \text{pixel} = A \exp (j \phi \vec{p}) \]

\[ \Rightarrow \text{HH}_\text{HH}, \text{VV}_\text{VV} \text{ and HV}_\text{HV} \text{ interferograms/coherence maps} \]
Coherence optimization by eigenvalue decomposition

Find the 3 orthogonal scattering mechanisms that optimize the coherence locally
Forest Height Retrieval

\[ \text{pixel} = A \exp \left( j \phi \right) p \]

+ allometric relationship for estimation of biomass

**Fig. 3.** Forest heights derived from the Pol-InSAR technique overlaid on a Google map from Traunstein, Germany (forest height retrieval based on two fully-polarimetric L-band data sets acquired by DLR’s airborne E-SAR system).
BelSAR : an Airborne Campaign for L-Band Full-Polarimetric and Interferometric Bistatic SAR Measurements over Belgium

for applications in
- agriculture
- soil moisture
- bistatic SAR science

5 flights covering one vegetation growth season
Combining **Radar** and **VIS-NIR data**: soil moisture, hydric stress, irrigation monitoring...

**Hyperspectral Data**
- **Post-processing**:
  - Atmospheric /radiometric/geometric corrections
- **Exploitation** (support to bio-certification, portable spectrometer)

Development of **synergy** between **geo-positioning and remote sensing data**
Academic at Liege University:
- Remote Sensing
- Cosmology
- Observing the Earth from Space
- Internship
- Seminars on Topical Issues

Lectures and B2B
- Santiago University (Chili)
- Belspo,
- Argentine,
- WAN,
- Algérie…

FabSpace 2.0 – Open innovation, Earth Observation Data Exploitation
Certificate Course on 
Technologies for Earth Observation from μ-Satellites
Certificate Course on Technologies for Earth Observation from μ-Satellites
Computers:

- 4 iMac 27”
- 1 MacBook Pro
- Exploitation system: MacOS10.12

Mass memory Stations:

- 1 Synology DS1515 + 9Tb effective (18Tb in RAID)
- 1 LaCIE 2big 2 x 3 Tb
Thank you